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**Patterns of Surface EMG Following
Muscular Endurance Training**

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Patterns of Surface EMG following
Muscular Endurance Training

by

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Report

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Muscular Endurance Training**

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The delayed occurrence of fatigue while maintaining submaximal force output is a function that could be driven by the central nervous system (CNS). It has been found previously that mean EMG amplitude increases with fatigue. Endurance time has also been found to increase over repeated testing. The purpose of this study was to compare the muscle activation patterns and endurance times after training of the AdP muscle. This study analyzed surface

EMG of the adductor pollicis (AdP) muscle in young, healthy adults during a sustained submaximal isometric fatiguing contraction before and after 4 weeks of muscular endurance task training. Eight participants (training group: $n = 4$ and control group: $n = 4$) carried out maximal voluntary contractions (MVCs) while sustaining isometric force of 20% MVC of thumb adduction before and after the four weeks of endurance training. EMG, recorded through surface electrodes, was measured before and after training in an effort to detect a possible CNS training effect. The endurance training group trained the AdP muscle at 20% MVC every other day for 4 weeks. Average force was calculated over 5 second time bins every 5% of endurance time (20 time bins total). A significant increase in endurance time was seen in the training group of this study. A significant effect of change for pre and post-training mean EMG amplitude across the two groups was found ($p < .001$). A significant interaction effect between pre and post training and control groups was also found ($p = .016$). There was also a significant deficit in increases of mean amplitude between the first and last time bins of the endurance task (pre and post) after training. This indicates that there is an effect of training on increasing endurance time which can be exhibited through changes in mean EMG amplitude.

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INTRODUCTION

Muscular resistance training has been found to activate earlier motor unit recruitment (Van Cutsem et al. 1998; Keen et al. 1994). The central and peripheral nervous systems, are known to respond to new patterns of muscular activity. During contractions when an individual contracts a particular muscle until exhaustion, there is adjustment in the motor unit firing rate as fatigue sets in (Carpentier et al. 2001, Fallentin et al. 1993, Garland et al. 1994, Garland & Miles 1997, Wesgaard & De Luca 1999). At the point of exhaustion an electromyogram (EMG) shows a lowering of activation of motor units (Bigland-Ritchie et al. 1986, Fugelevand et al. 1993). Neuromuscular function can be further understood by looking at the causes of delay in muscular fatigue. This would aid in the development of more effective and efficient rehabilitation tools that improve muscular endurance following neuromuscular disease or injury. No study to date has looked at how amplitude of force changes over endurance time as a result of muscular training.

The existence of a lowering in activation at exhaustion has proven that endurance time can be prolonged in accordance with the lowering of the rate of activation. After repeat performances of the task, EMG amplitude showed a progressive deficit as exhaustion approached as well as an extension in time until fatigue (Hunter & Enoka 2002). This brings into question how a muscle might function after a legitimate training session is imposed. Endurance training might also increase excitability of the spinal cord. It is possible that changes in EMG amplitude may contribute to sustaining sub-maximal force after training. While Hunter and Enoka (2002) found that rate of fatigue changes between after repeat performances, no study to date has implemented a training program to see how rate of fatigue changes in regards to muscle contraction while looking at EMG mean and max amplitudes. Endurance time was found by Hunter and Enoka to significantly increase after repeated fatigue performances.

The Purpose of this study was to determine changes in surface EMG of the adductor pollicis (AdP) muscle during a sustained sub-maximal fatigue task before and after four weeks of training in an effort to prove a training effect exists at the level of the CNS (Sogaard et al. 2006). Only the EMG of the AdP muscle was analyzed in this study. We hypothesized that, after training, the mean and

max EMG amplitude would show a greater lowering or deficit in motor unit firing rates as compared no training in accordance with onset of exhaustion during a submaximal isometric contraction.

METHODS

Participants

Eight healthy individuals of age 23.4 ± 0.9 years participated in this study. Participants were randomly assigned to training ($n=4$) and control groups ($n=4$). The training group was comprised of 2 males and 2 females and the control group consisted of 3 males and 1 female with a mean age of 24.3 ± 1.8 years. These volunteers were all healthy and had no medical history of injury to the non-dominant hand (the hand tested) or any metabolic or neurological disorders that might have affected the accuracy of the results. Also, the volunteers had no history of thumb or hand training prior to testing. Musicians and athletes with a highly trained non-dominant hand were also excluded from the study. All subjects signed an informed consent form before beginning experimentation and attended an orientation session to become familiar with the procedures of the experiment. All procedures in this study were approved by The University of Texas at Austin Internal Review Board and were in accordance with the Helsinki Declaration.

Experimental arrangement

Participants were first seated in a chair with their non-dominant forearm supported in a custom-made splint with the placement of the wrist in a supinated

position. Straps over the wrist, forearm, upper arm, and shoulder held the limb in place with proper hand position. Therapeutic hand putty was also placed around the hand and fingers to prevent the hand from slipping during experimentation. The positioning of the wrist allowed for the thumb to be abducted and positioned against a metal strain-gauge force transducer. A ground surface electrode was placed on the ulnar styloid process of the wrist while a pair of pre-gelled, adhesive, Ag/AgCl disposable surface electrodes (Danlee Products, Inc., Syracuse, NY, USA) were placed on the palm of the hand just over the AdP muscle. Intramuscular insulated stainless steel fine-wire (0.002 mm) electrodes (California Fine Wire Company, Grover Beach, CA) was made of fines wires which were used to record data from a single motor unit. The wires were inserted with a thin hollow needle (25g) through the skin and into the muscle of the AdP of the hand. A surface-stimulating electrode was then held in place by a strap over the ulnar nerve at the wrist. A computer screen displaying a visual of the force and EMG was provided as a source of feedback for the subject.

Experimental Procedures

Participants familiarized themselves with performing and holding MVCs and isometric contractions. The participants were asked to return to the

laboratory after at least 48 hours post orientation.

Stimulation in this experiment was submaximal, meaning it was at stimulation with intensity that was 10% higher than that required to evoke a maximal M-wave (predetermined). Five single twitches were then given with a single pulse surface stimulation via the ulnar nerve at the wrist. A total of three MVCs were then performed for three about seconds each using the AdP muscle. MVCs were held with as much force as possible with the thumb adducting against the metal strain gauge bar.

After about seven minutes of rest, participants then performed during a fatigue task that consisted of isometrically contracting at 20% MVC until they reached the exhaustion. Endurance time was identified to be when two force fluctuations of 10% MVC or greater occurred within ten seconds of each other. For maximum effort, verbal encouragement was given to the participants during the fatigue task. MVCs as performed before the fatigue task were performed again immediately after the fatigue task.

The same experimental protocol was utilized for the pre and post-test with

the post-test being performed two days after the last training day. No one in the control group participated in the training. The control group performed only the pre-test and post-test without training and did so approximately four weeks apart.

Muscular Endurance Training Protocol

Training consisted of a total of 14 sessions where the AdP muscle of the non-dominant thumb was worked every other day for 4 weeks. Muscular endurance training was performed using a portable, custom-designed and built (University of Texas Mechanical Engineering Department, Austin, TX), thumb-training device, which isolated thumb adduction.

The training protocol for muscular endurance consisted of performing three sets of seven one-minute isometric adducting thumb contractions at 20% of MVC. Each set was followed by a two-minute rest interval and each repetition was followed by a five second rest interval. A monitor was placed in front of the participants to incorporate visual feedback about of the force they were exerting via a gauge on the training device. This allowed them to maintain a target force level throughout the isometric contraction. Every other training session was conducted in the laboratory under the supervision of the experimenter to ensure

that training was performed correctly. The other sessions were conducted at home. Participants were given the training device, a training log to record their training, and a hand-held stopwatch.

Data Analysis

Mean single motor unit firing frequency was analyzed off-line during a 5s time bin every 5% of endurance time. There were 20 time bins total. The first 5% segment of the fatigue task was designated the initial motor unit firing frequency, the last 5% segment of the fatigue task was designated the final motor unit firing frequency, and the 5% segment with the lowest mean motor unit firing frequency was designated the minimum motor unit firing frequency. Mean amplitude was taken from each time bin and recorded in an effort to assess the rate of fatigue. Only the surface EMG will be presented in this study. Motor units were analyzed in a separate study in our laboratory.

Statistical Analysis

Data are reported as means \pm SE in the figures. On the basis of distribution of the change in EMG amplitude, subjects were categorized as those who underwent training and the control group. A two-way repeated measures ANOVA was used with time x group as the independent factors to test pre/post

training differences in mean and max EMG amplitude between the training and control groups. Bonferroni corrections were used for post hoc analysis of multiple comparisons. An alpha level $p \leq 0.05$ was accepted as the level of statistical significance.

RESULTS

The purpose of this study was to compare changes in muscle activation and endurance time after endurance task training. Endurance times are first analyzed before the associated changes in muscle activation through changes in force amplitude.

Endurance Times. There was a significant difference ($p < .001$) in endurance times between the pre and post-test in the training group. This was not seen in control group. Every participant in the training group showed a significant increase in endurance time after training whereas none of the control subjects showed significant improvement. The mean difference for both groups is represented in Figure 1.

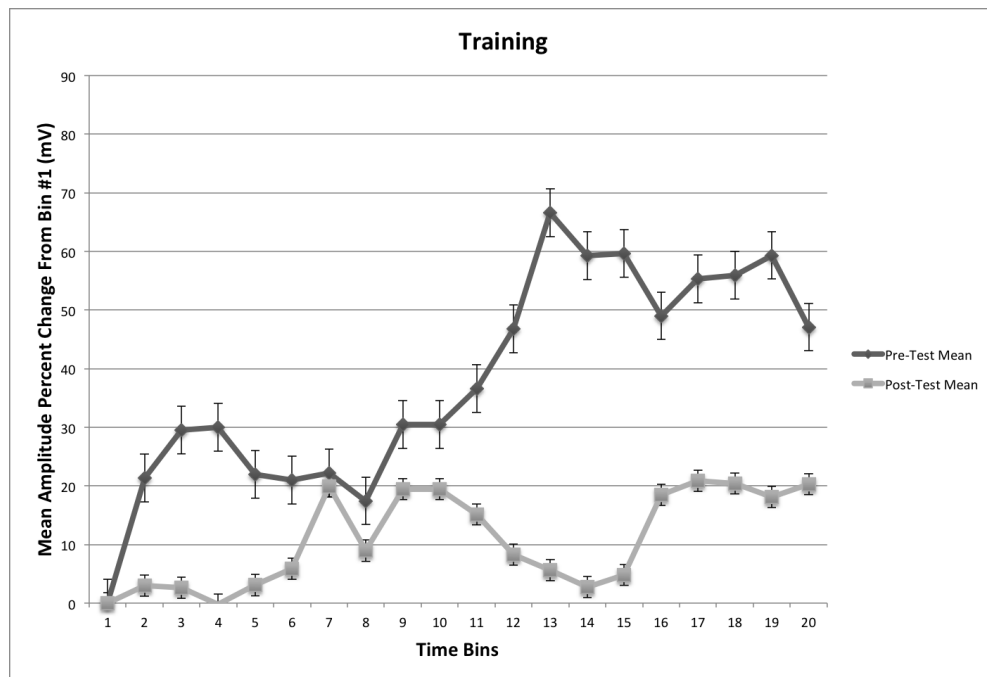


Figure 1.

Mean EMG Amplitude. A significant effect of change for pre and post mean EMG amplitude across the two groups was found ($p < .001$) with a lower overall mean amplitude being found in the training group. A significant interaction effect between pre and post testing and the lengthening of duration of endurance times was also found ($p = .016$) in the training group. There was also a significant interaction of mean EMG amplitude between the first and last time bins in training

measures ($p < .001$). A visual representation of percent change between the first time bin and each subsequent time for mean amplitude can be found in Fig. 4 and Fig. 5. A deficit in mean EMG amplitude is seen more in the post-training group as compared to the control which showed no significant difference.

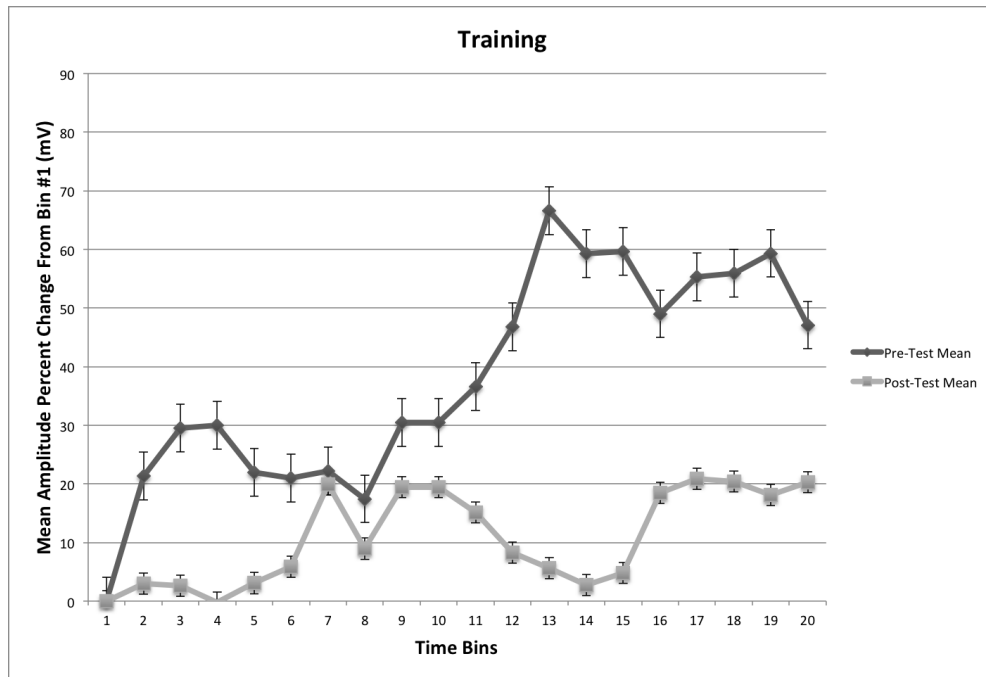


Figure 2.

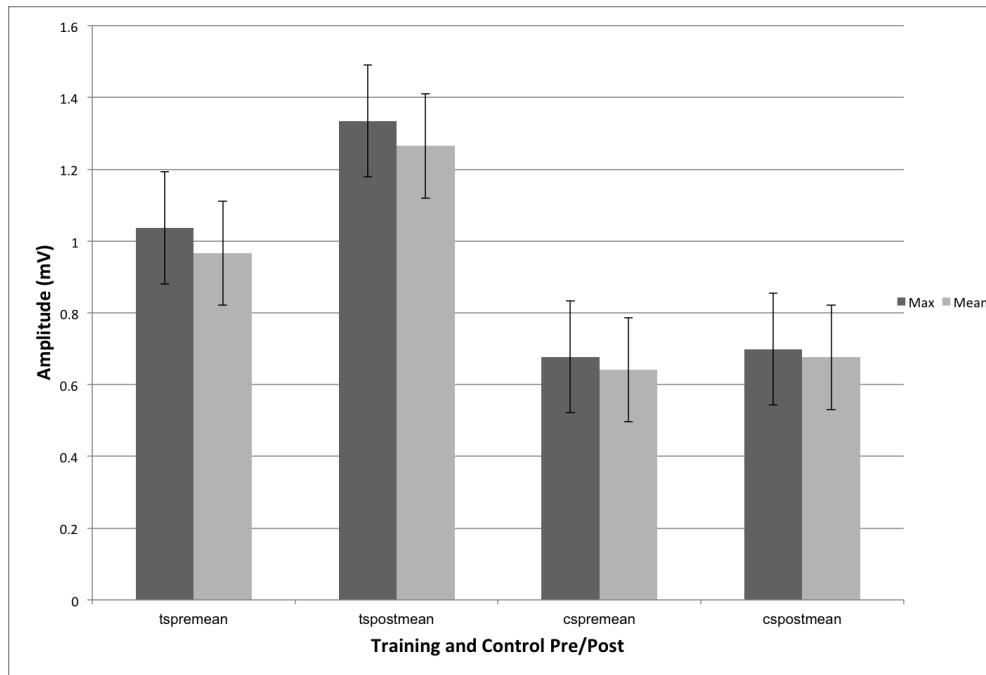
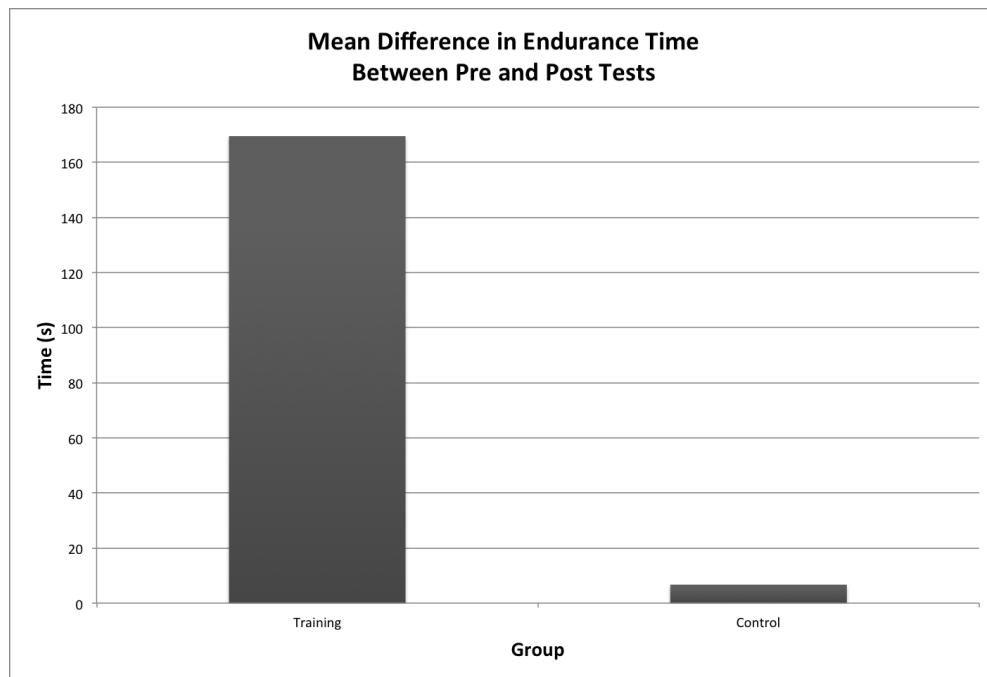


Figure 3.

Post-hoc comparisons revealed no individual differences during training, but there was an overall effect between training and endurance time. There was no significant difference found in max EMG amplitude possibly due to a learning effect. Pre-fatigue mean and maximum amplitudes were also compared between training and controlled participants. While a difference appears to exist in Figure 4, it was not significantly significant.



$tspremean$ = pre-training group mean amplitude, $tspostmean$ = post-training group mean amplitude, $cspremean$ = pre control mean amplitude, $cspostmean$ = post control mean amplitude

Figure 4.

DISCUSSION

The purpose of this study was to compare the muscle activation patterns and endurance times after training of the AdP muscle. Hunter and Enoka looked at the amplitude of EMG for muscular contractions after repeated trials took place and found differences in firing rates and the extension of endurance times. This study is the first of its kind to implement a muscular endurance training protocol through a sustained submaximal voluntary fatigue task. The results show that details of the EMG amplitude activity during submaximal isometric contractions can vary with training and that these adjustments are in accordance with changes in endurance time. After seeing that there are small increases in the rate of single motor unit firing rates after endurance training (Mettler and Griffin, in press), the question of using mean amplitude in accordance with the onset of fatigue was then answered in this study.

Mean amplitude was found to be an indicator of the onset of fatigue. A deficit in recorded mean EMG amplitude levels was found after a training program was imposed. Participants who participated in the training program also showed

lengthened endurance times. Mean amplitude was proven to rise at a much lower rate while endurance time elongated. This is a strong indicator that a training effect happens at the level of the CNS instead of the peripheral nervous system.

The general pattern in the percent difference in mean EMG amplitude was that it increased at a lesser rate post endurance training than that of the control group as indicated in Fig. 1 and Fig. 2. This difference is visually present with there being a significant difference found between each of the twenty 5-second time bins used as well as between the first time bin, the tenth time bin, and the twentieth time bin.

There was also significance found between pre and post testing in either training or the control group. This is relative to the fact that muscular endurance did become longer after training in Hunter and Enoka's study. Higher muscular endurance did result in an increase in mean motor unit firing rates and a lower rise in mean amplitude. With that being said, the mean EMG amplitude pattern

observed in the study was consistent with previous findings of sub-maximal isometric fatiguing contractions in young adults (Garland et al. 1997; Griffin et al. 2000; Adam and DeLuca 2005), as well.

Muscular fatigue during submaximally sustained contractions could be linked to central nervous system fatigue. Endurance training leads to a greater excitability of the spinal cord as compared to sedentary and power-trained individuals and could allow for longer muscular contractions and activation over a longer amount of time (Rochcongar et al. 1979; Mafiuletti et al. 2001). Therefore, increases in central nervous system drive could decrease fatigue and allow for a longer endurance time for muscular contractions. Longer endurance times were found after training in this study. Endurance training has been proven effective and mean EMG amplitude is a proven indicator of fatigue in surface EMG. This is an extension of what Hunter and Enoka (2002) found with the main difference being that actual training was used to come to these conclusions. Neuromuscular function can be further understood by looking at the causes of delay in muscular fatigue. This information is detrimental in the development of effective rehabilitation tools for improving muscular endurance following neuromuscular

disease or injury.

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